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V/STOL AIRCRAFT AND THE PROBLEM OF JET-INDUCED SUCKDOWN

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INTRODUCTION

The purpose of this paper is to describe the suckdown condition encountered when jet-propelled, Vertical/Short Takeoff and Landing aircraft hover near the ground. A discussion of this ground effect problem and how it is being investigated will be followed by a more detailed description of one of the methods researchers are using to investigate the basic mechanisms that influence the suckdown condition. Specific parameters that will be taken into account include the height of the jet above the ground, jet exit conditions, and model geometry. Data from a current investigation will be presented along with some conclusions from other recent investigations in order to relate the significance of some of the parameters influencing suckdown. Suggestions will be made for some additional testing methods which might be useful to researchers investigating the mechanisms involved in jet-induced suckdown.

BACKGROUND

In the Vertical/Short Takeoff and Landing (V/STOL) aerodynamics field, aircraft utilizing jet propulsion configurations are still in the process of being perfected (fig. 1). Though aircraft such as the Harrier have already been produced, researchers are still investigating the many problems inherent to the jet propelled V/STOL concept. One of the biggest problems currently under investigation is the condition known as "suckdown."

Suckdown is the negative lift induced when a jet propelled V/STOL aircraft is in hover just above the ground ("ground effect"). The negative lift, or down load, characteristic is a result of the entrainment of the surrounding air by the jet exhaust. When a V/STOL aircraft is in ground effect, the jet exhaust impinges on the ground and forms a stream of air that is called a "wall jet," in which air flows radially outward along the ground. As illustrated in figure 2, both the vertical jet stream and the wall jet entrain air, that is, they pull ambient air into their flow pattern.

The induced flow if air results in an area of low pressure directly underneath the aircraft. Meanwhile, the relatively motionless air above the aircraft results in a higher pressure than that of the air below. The product of the unequal pressures is a down load which acts against the lift created by the jets. The down load produced out of ground effect is not a problem due to the absence of a wall jet. The wall jet is significant because it greatly increases the surface area of flowing air which allows for a greater entrainment of the ambient air.

The problem of suckdown cannot be ignored. It results in loss of a jet V/STOL aircraft's net lifting capability in ground effect. Payload, handling, and control are also restricted by suckdown. Therefore, many investigations have been and are currently being performed by researchers in hopes of learning more about the factors influencing suckdown. Once researchers understand all of the factors, they will formulate some method to compensate for or overcome the induced down load. Due to the complicated flow field produced by multiple-jet configurations (fig. 2-b) (all current jet propelled V/STOL aircraft have two or more exhaust ducts), researchers often use basic models with just one jet (fig. 2-a) and a simple, flat planform in the shape of a circle or rectangle which represents the lower surface of the aircraft.

SINGLE-JET SUCKDOWN

Single-jet suckdown investigations represent a simplified method for the examination of a complex problem. This method has both positive and negative aspects. The single-jet approach is extremely useful for analysis of jet characteristics and other basic mechanisms which influence suckdown. On the other hand, such an approach completely omits the vital "fountain" characteristic (fig. 2-b) which accompanies multiple-jet configurations. The fountain is formed when two or more radial wall jets meet and force their air flows vertically upward. Such an upward stream of air can actually reduce some of the down load on the aircraft by counteracting it with an upward force. Moreover, because so many added complications are involved with multiple jets and fountains, the single-jet configuration is necessary to study the roots of the suckdown problem so a reliable database may be developed for reference in future investigations with more complicated configurations.

The investigations of single-jet suckdown have revealed certain unforeseen complications. Basically, the margin of error between the large-scale tests, small-scale tests, and calculated predictions was found to be larger than what is permitted. Large- and small-scale tests need to produce results that closely agree; otherwise expensive, large-scale models have to be constructed each time an investigation is to be performed. The situation is almost identical in reference to calculated predictions. The margin of error between the calculated predictions of researchers and their test results indicates that they are not taking into account all of the factors that influence suckdown. Either the researchers aren't aware of all of the factors involved or they just don't understand suckdown characteristics well enough to develop reliable methods for predictions. It seems that the influence of ground proximity on jet-induced lift-loss is so great that normal empirical methods are no longer effective. Owing to this dilemma, researchers are focussing their attention on the formation of an improved database which will include the effects of all of the influencing parameters. If more reliable information is thus made available, prediction methods that are based on more than just straight empiricism may be developed. A more inclusive database will allow researchers to investigate the margin of error between large- and small-scale tests in order to correct the problem.

The prediction methods used previously have proved to be unreliable. The first definitive prediction method for jet-induced suckdown in ground effect was developed by Wyatt (ref. 1). He showed how planforms with various diameters could be correlated on the basis of the height and diameters of the planform and jet. Though the basic framework for Wyatt's correlation has not be contradicted by investigations that have been run, his method doesn't account for all of the variables that affect suckdown. The jet pressure ratio, exit velocity distribution, size of the ground plane, and jet-induced turbulence are not represented as they should be in Wyatt's equation (ref. 2). The very same factors are not completely understood as of yet, but they are known to have an important influence on the flow field. Thus, researchers have been comparing their test results to a method that is not inclusive. This fact could explain why test data don't match prediction data.

The database used for large-scale investigations has been based on some questionable test results. The test results stated that a small-scale, cold, single-jet test could produce results that match full-scale data. The test this statement was based on produced lift-loss differences of three to five percent between the large- and small-scale tests run. Such a percentage of error is not acceptable and proves the test invalid. It has been shown that a mere two percent error in lift-loss predictions could translate into a ten percent reduction in payload capacity (ref. 3). Thus, the database that researchers use as a reference when performing investigations is virtually useless. This fact could help to explain the margin of error that exists between large- and small-scale investigations.

At the NASA Ames Research Center in California, researchers are currently analyzing the results from recent single-jet investigations they have performed in their outdoor test facility. Two sets of tests were run, a set of large-scale tests and a set of small-scale tests, in order to study the effects of scaling on jet propulsion, ground effect testing. The set of large-scale tests was made up of several runs using a YJ-97 turbojet for half of the testing and a TF-34 turbofan for the rest. To match the large-scale testing, the set of small-scale tests were divided into different types of air flow turbulence. The runs creating a less turbulent flow were to be compared with the turbojet, while the runs created with a greater turbulence level were to be compared with the turbofan tests. Both sets of tests were run using a square plane to represent the ground and a circular plane to represent the lower surface of an aircraft, and had a jet exit flush with the plane in the center of the circle. The two flat surfaces were parallel to each other and positioned at a ninety-degree angle from the ground (figs. 3 and 4). Though much of the data from the tests is still being analyzed, some conclusions have already been drawn.

Results from many recent tests, including the ones performed at NASA Ames, are the source of a constant flow of updated information that should produce a reliable database for future investigations. This information includes a much better understanding of many important parameters that influence the calculation of suckdown characteristics, new insights into which parameters influence scaling effects, and indications that investigation methods could be revised to acquire more precise data. Some of the more prominent parameters now being studied are the height of the jet above the ground, jet exit conditions, and model geometry.

The height of the jet and suckdown plate above the ground proved to be an important parameter that influences suckdown. As the height increases, the induced down load decreases (fig. 5). The distance between the lower surface of the aircraft and the ground also has a key role in the process of suckdown. A decrease in the distance between the aircraft and the ground produces a need for an increase in the jet velocity, which in turn causes the air flow beneath the aircraft to move faster; faster moving air translates into lower pressure; lower pressure produces loss in height; and so the cycle continues. Though there are quite a few more parameters involved in the process that produces suckdown, this basic theory of infinite suckdown is valid. The fact that lower heights increase suckdown encourages researchers to favor an aircraft with higher wings.

There are several jet exit conditions that should be considered when evaluating jet-induced suckdown. A few of the more important exit conditions that are currently being studied are the nozzle pressure ratio (NPR), jet turbulence, and the exit pressure profile. The nozzle pressure ratio is the area-weighted average of the total pressure across the nozzle exit. In simple terms, NPR is a single value that represents the average pressure at the jet exit. Researchers are not all in agreement about the influence of the nozzle pressure ratio, though most agree that NPR has little effect on the ratio of lift-loss to base thrust. Part of the problem is that the lift-loss is linear with NPR, but thrust isn't, which introduces nonlinearities when the lift-loss is nondimensionalized by thrust. This effect is illustrated in figure 6. Jet turbulence is considered an important factor involved in creating the differences between large- and small-scale tests. The turbulence created by the jet affects the air flow pattern beneath the aircraft and thus affects the suckdown condition produced. Large-scale tests utilize real jet engines while small-scale tend to use compressed air to simulate jets; this difference in sources results in completely different jet-induced turbulence levels. Researchers have discovered that the use of screens will affect the turbulence a jet produces, but not in any uniform manner which would allow them to manipulate the situation. A method of controlling the jet exit turbulence level needs to be derived in order to produce equivalent turbulence levels for large- and small-scale tests that are to be compared. The nozzle pressure profile is the actual distribution of total pressure across the nozzle exit. In other words, it is a set of numbers that represent the varying pressure at the nozzle exit. Nozzle pressure profiles should be matched for tests that are to be compared in order to ensure equivalent suckdown characteristics involving pressure.

The shape and size of the model parts used in testing have been determined to greatly influence investigation results. The ground plane should be quite large in order to accurately simulate a landing pad. The jet to suckdown plate diameter ratios should be the same for tests that are going to be compared. Researchers consider model geometry to be one of the important factors causing the differences between large- and small-scale tests. For accurate analysis, researchers recommend that the suckdown plate be close to the form of an aircraft, not a flat circle or rectangle such as most current models use.

CONCLUSION

In the Vertical/Short Takeoff and Landing field of aerodynamics, jet-induced suckdown is a subject of intense study. In the course of this study many discrepancies between prediction and large- and small-scale results were discovered. Before researchers would be able to resolve the discrepancies, they would need to gain a better understanding of the basic mechanisms that produce suckdown in ground effect. To begin to gain an understanding required that the researchers perform very basic investigations and slowly build a thorough and reliable database. The investigations that followed utilized single-jet test models with basic geometries. As the investigations continued, the data collected were analyzed and testing methods were upgraded. Recent investigations indicate that several parameters need to be examined in greater detail, and more realistic, scaled model geometries should be used. Now that a reliable database is being compiled, researchers will be able to expand testing methods back to models with multiple jets and this time they will have a greater ability to draw accurate conclusions.

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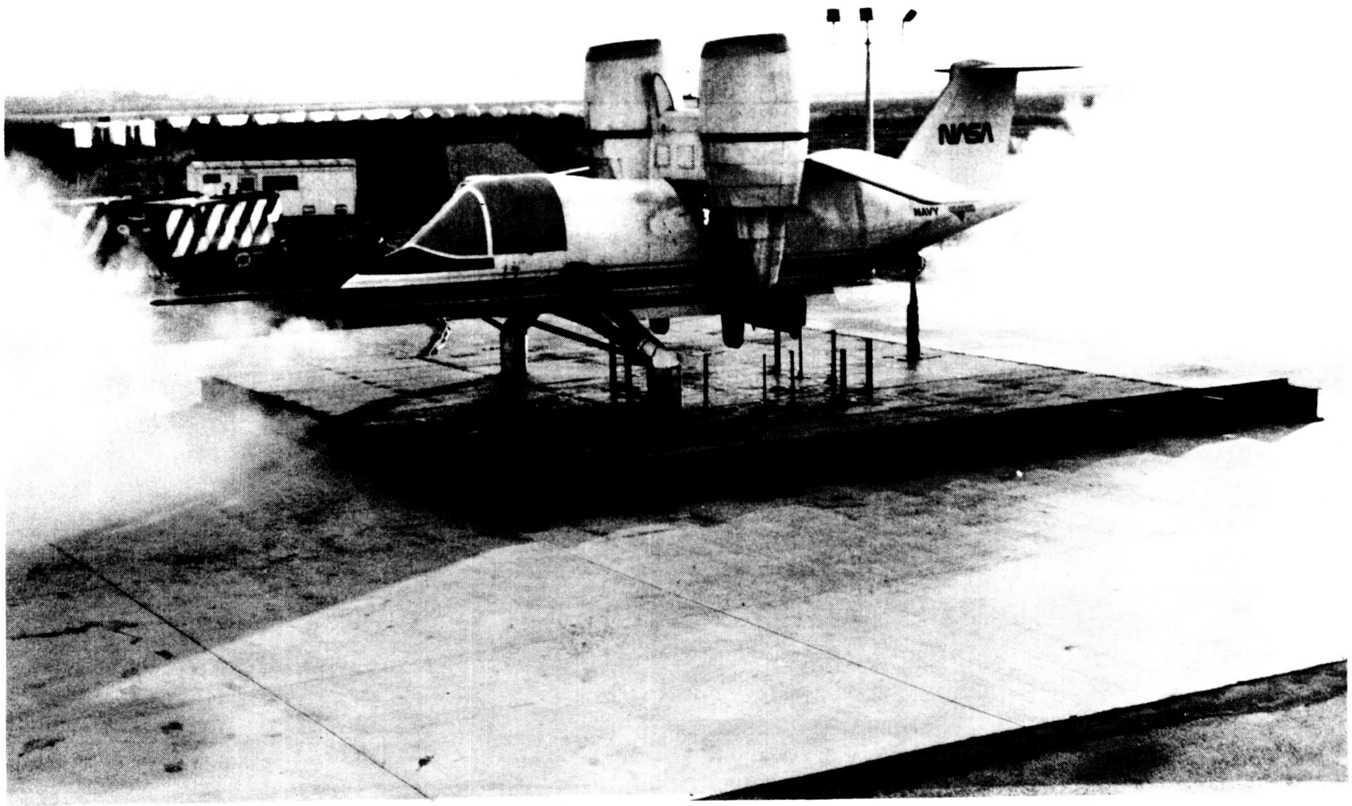

Figure 1.- Grumman twin tilt-nacelle V/STOL aircraft test model.

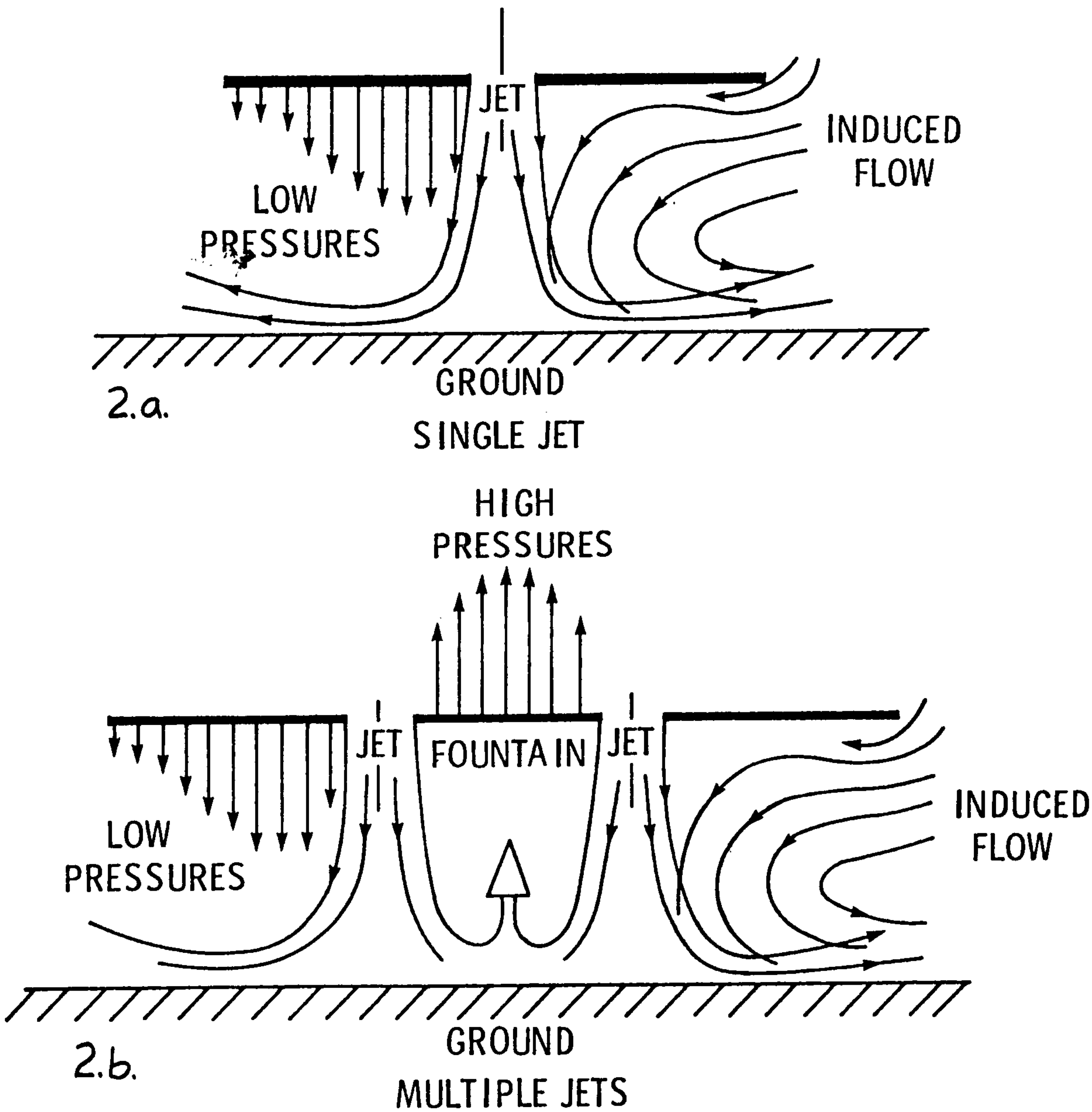

Figure 2.- Flow patterns near ground with single jet and with multiple jets (ref. 5).

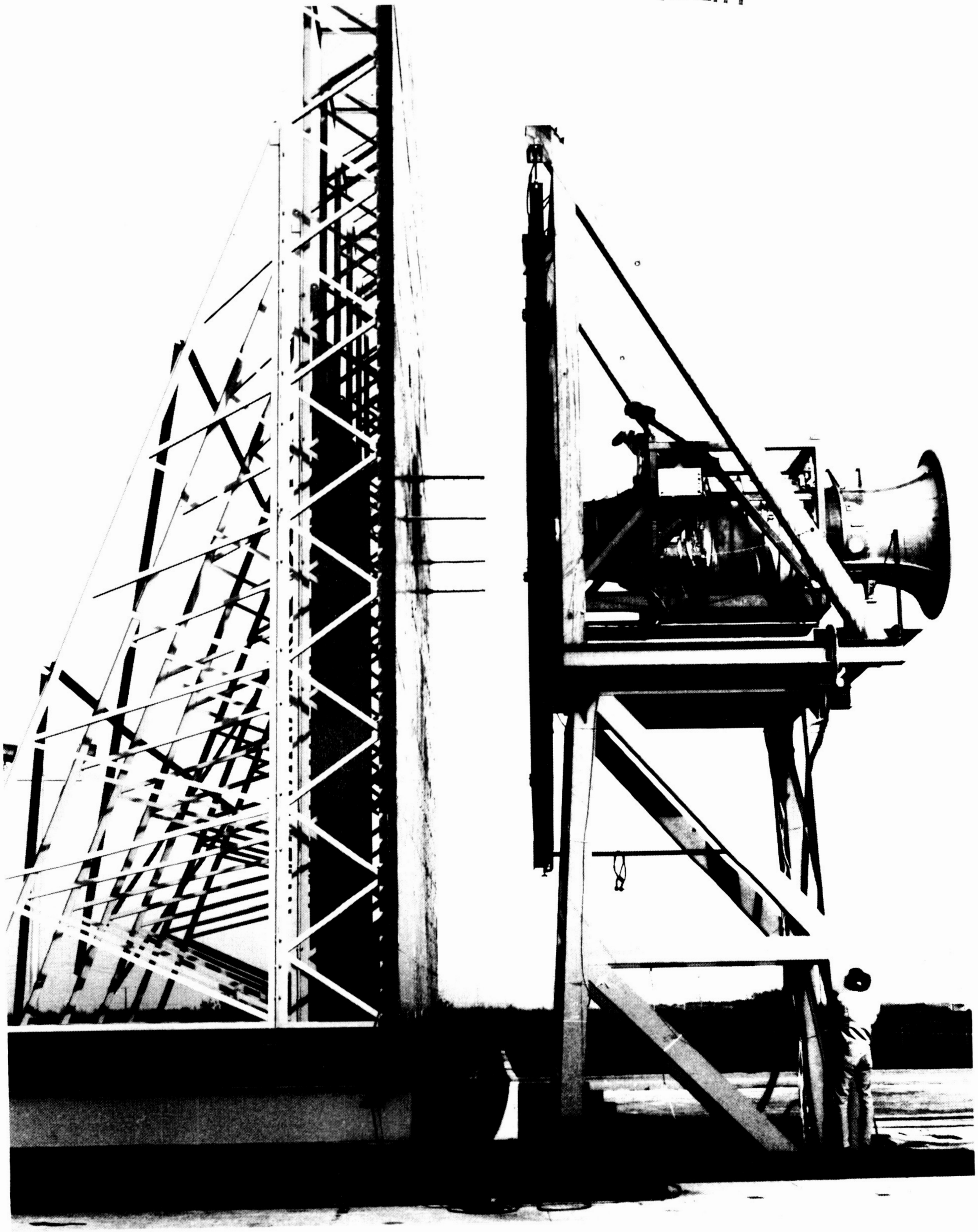

Figure 3.- Large-scale, single-jet test model with TF-34 at the NASA Ames outdoor test facility.

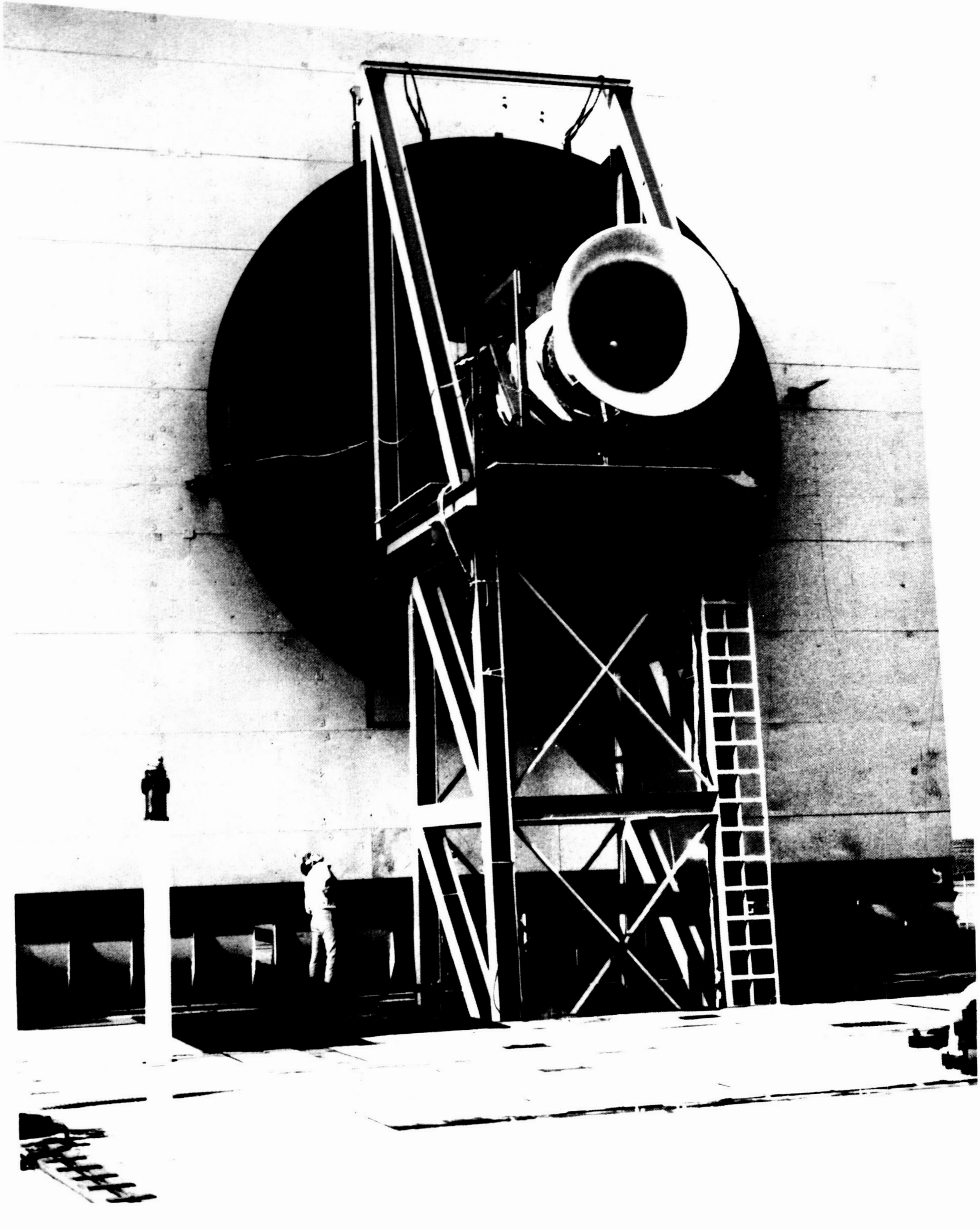

Figure 4.- Perspective 2.

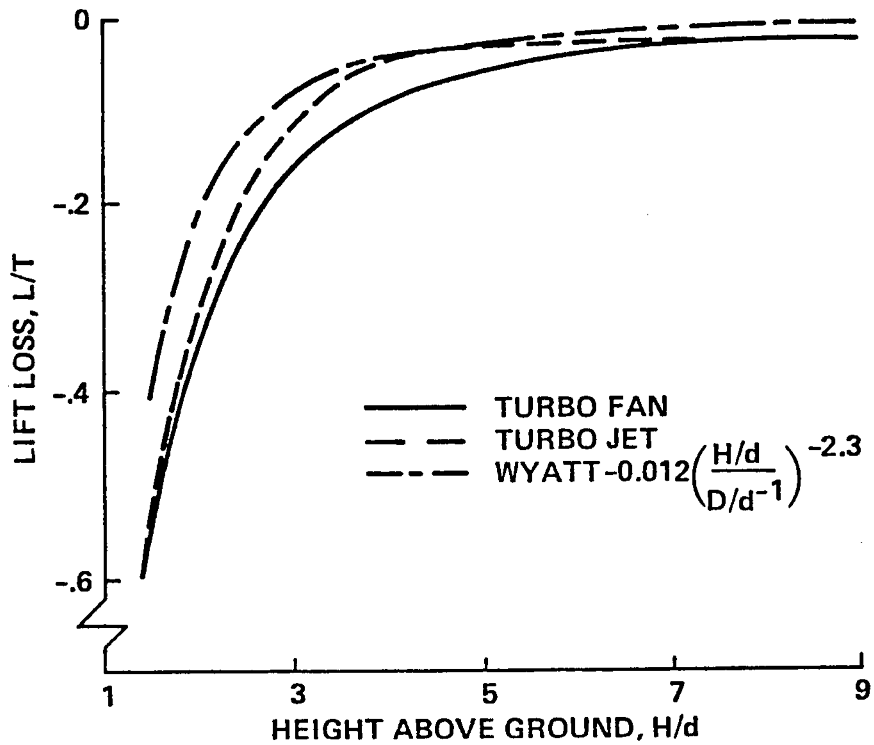

Figure 5.- Lift-loss vs height--as the value for height increases, the amount of negative lift decreases.

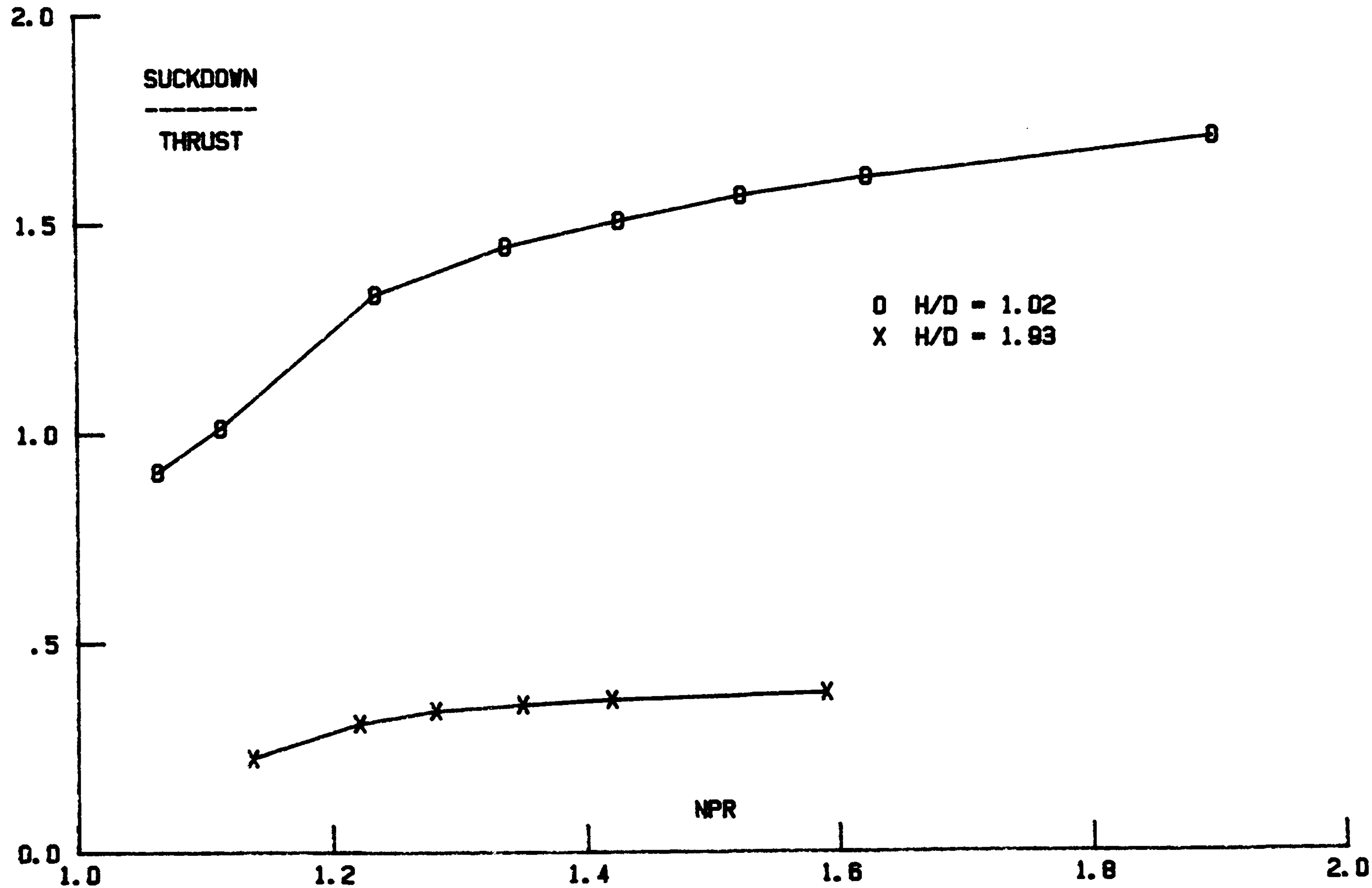

Figure 6.- Lift-loss to base thrust ratio vs NPR--the ratio value changes with changing NPR.